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TRANSMITTAL FORM

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ENCLOSURES *(check all that apply)*

- ☐ Fee Transmittal Form
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Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

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Signature	Jacqueline E. Hartt
Date	November 13, 2001

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service with sufficient postage as first class mail in an envelope addressed to: Commissioner for Patents, Washington, D.C. 20231 on this date: November 13, 2001

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AUSTRALIA

#5

1-14-02

Patent Office
Canberra

I, JONNE YABSLEY, TEAM LEADER EXAMINATION SUPPORT AND SALES hereby certify that annexed is a true copy of the Provisional specification in connection with Application No. PR 0018 for a patent by STRUCTURAL MONITORING SYSTEMS LTD filed on 08 September 2000.

WITNESS my hand this
Twenty-fifth day of October 2001

J R Yabsley

JONNE YABSLEY
<u>TEAM LEADER EXAMINATION</u>
<u>SUPPORT AND SALES</u>

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APPLICANT: Structural Monitoring Systems Ltd

AUSTRALIA

PATENTS ACT 1990

PROVISIONAL SPECIFICATION

FOR THE INVENTION ENTITLED:

"METHOD AND APPARATUS FOR MONITORING THE INTEGRITY OF STRUCTURES"

The invention is described in the following statement:-

Title

METHOD AND APPARATUS FOR MONITORING THE INTEGRITY OF STRUCTURES

Field of the Invention

The present invention is for a method and apparatus for monitoring the integrity of a structure, and in particular to a structure having one or more internal cavities or composed of an ensemble of components between which one or more cavities exist or can be created.

Background of the Invention

The present invention has its genesis from consideration of the problems faced by aircraft designers in monitoring the integrity of: sandwiched structures typically encountered around splices and cut-outs in fuselages; and, substantially hollow components as encountered in composite structures such as flaps, doors, panels and the like; and in attempting to prevent in the ingress of moisture into such structures and components. These structures and components are difficult to examine for the detection of cracking corrosion and disbonding. Further they are prone to the ingress of moisture arising for various reasons including:

- capillarity and the substantially hollow nature of the structures, particularly those made from composite materials;
- exposure to temperature extremes;
- exposure to large ambient pressure variations;
- exposure to environments of high humidity and precipitation.

Apart from corrosion in metallic structure, the ingress of moisture can lead to serious structural flaws such as disbonding due to progressive damage caused by the cyclic ingression of the moisture followed by expansion as it freezes.

Of course the above problems are not the exclusive domain of aircraft designers. Structural integrity monitoring has very wide application and can be used, for example, to monitor the adhesive bonds such as between anechoic tiles on submarine or heat

resistant tiles on a spacecraft.

Summary of the Invention

It is an object of the present invention to provide a method and apparatus for monitoring the integrity of the structure.

According to a first aspect of the present invention there is provided a method of monitoring the integrity of a structure disposed in an environment containing a fluid at an ambient pressure, said structure having at least one internal cavity, said method including at least the steps of:

providing a source of a first fluid at a first pressure greater than said ambient pressure;

placing said at least one cavity in fluid communication with said source; and

monitoring for a change in a steady state rate of inflow of said first fluid into said at least one internal cavity.

Preferably, the said first fluid source pressure is substantially constant with respect to said ambient pressure.

In one embodiment, said monitoring step includes coupling a high fluid flow impedance in series between said at least one cavity and said source, to create a steady state differential pressure between said at least one cavity and said source, and monitoring for a change in said steady state differential pressure.

Preferably, said step of providing said first fluid source at said first pressure includes setting said first pressure at a level which is sufficiently greater than said ambient pressure to overcome hygroscopic force and capillarity, but not sufficient to be detrimental to the integrity of said structure.

Preferably, said step of providing said source of first fluid comprises providing a source of a first gas.

Preferably, said step of providing said first gas includes providing a moisture trap between said source and said at least one cavity to dry said gas prior to flowing into said at least one cavity.

Preferably, when said structure includes two or more internal cavities, said placing step includes one or both of (a) placing said internal cavities in fluid communication with each other; and (b) placing said cavities in fluid communication with said source.

In an alternate embodiment, said monitoring step includes:

providing a supply of a fluid marker in fluid communication with said source; and

monitoring said structure for traces of said fluid marker.

Preferably said fluid marker includes a dye indicating liquid or gas.

In a further alternate embodiment said step of monitoring for a change in steady state inflow includes:

providing a supply of a detectable gas in fluid communication with said source;

providing a detecting means for said gas; and

monitoring for a change in a steady state rate of seepage of said gas from said structure.

According to a further aspect of the present invention there is provided a method of monitoring the integrity of a structure disposed in an environment containing a fluid at an ambient pressure, said method including the steps of:

forming a sealed cavity in said structure;

providing a source of a first fluid at a first pressure greater than said ambient pressure;

placing said at least one cavity in fluid communication with said source; and,

monitoring for a change in a steady state rate of inflow of said first fluid into said cavity.

Preferably said step of forming said sealed cavity includes forming a recess or depression and forming a seal across said recess or depression.

According to a further aspect of the present invention there is provided a method for monitoring the integrity of a structure disposed in an environment containing a fluid at an ambient pressure, said structure being an ensemble of two or more components which are coupled together, said components juxtaposed relative to each other in a manner so that a surface of one component is adjacent to a surface of at least another one of said components to form respective adjacent surface pairs, said method including the steps of:

forming one or more cavities between one or more of said adjacent surface pairs;

providing a source of a first fluid and a first pressure greater than said ambient pressure;

placing at least one of said cavities in fluid communication with said source to produce at least one source pressure cavity; and

monitoring for a change in a steady state rate of inflow of said first fluid into said at least one source pressure cavity.

Preferably said method further includes the step of placing alternate ones of said cavities in fluid communication with said ambient pressure to produce adjacent interspersed source pressure cavities and ambient pressure cavities.

Preferably said method further includes the step of placing a moisture trap in series connection between said ambient pressure cavities and said environment or a source of said ambient pressure.

Preferably, said monitoring step includes coupling a high fluid flow impedance in series between said source pressure cavities and said source, to create a steady state differential pressure between said source pressure cavities and said source, and monitoring for a change in said steady state differential pressure.

In an alternate embodiment, said monitoring step includes providing a supply of a fluid

marker in fluid communication with said first fluid source and monitoring said structure for traces of said fluid marker.

Preferably, when said components of said structure, are coupled together by a layer of adhesive, or incorporate a layer of sealing material between said adjacent surface pairs, said forming step includes forming said cavities in said adhesive or sealing layer.

Preferably where said components are coupled together by mechanical fasteners, said forming step includes providing a seal about said adjacent surface pairs to form said cavities between said adjacent surface pairs.

According to a further aspect of the present invention there is provided an apparatus for monitoring the integrity of a structure disposed in an environment containing a fluid at an ambient pressure, said structure having at least one internal cavity, said apparatus including at least:

a source of a first fluid at a first pressure greater than said ambient pressure;

a communication channel for providing fluid communication between said source and said at least one cavity; and

monitoring means for monitoring for a change in a steady state rate of inflow of said first fluid through said channel into said at least one internal cavity.

In one embodiment, said monitoring means includes a high fluid flow impedance disposed in said channel in series between said at least one cavity and said source, said high fluid flow impedance creating a steady state differential pressure between said at least one cavity and said source, and transducer means coupled across said high fluid flow impedance for monitoring for a change in said steady state differential pressure.

Preferably said first pressure is sufficiently greater than said ambient pressure to overcome hygroscopic force and capillarity but not sufficient to be detrimental to the integrity of said structure.

Preferably said first fluid is a gas.

Preferably said apparatus further includes a moisture trap located between said source and said at least one cavity to dry said gas prior to flowing into said at least one cavity.

In an alternate embodiment, said monitoring means includes a fluid marker in communication with said source for marking said structure at locations where said fluid permeates from said cavity through said structure to said environment.

According to a further aspect of the present invention there is provided a method of inhibiting the ingress of a target fluid into a structure disposed in an environment containing said target fluid at an ambient pressure, said structure having at least one internal cavity, said method including the steps of:

providing a source of a first fluid at a first pressure greater than said ambient pressure; and

providing a fluid communication path between said at least one internal cavity and said source.

Preferably said method further includes the step of monitoring for a change in a steady state rate of inflow of said first fluid into said at least one internal cavity thereby facilitating the monitoring of the integrity of said structure.

According to a further aspect of the present invention there is provided an apparatus for preventing the ingress of a target fluid into a structure disposed in an environment containing said target fluid at an ambient pressure, said structure having at least one internal cavity, said apparatus including at least:

a source of a first fluid at a first pressure greater than said ambient pressure; and

one or more communication channels for providing fluid communication between said source and said at least one cavity.

Brief Description of the Drawings

Figure 1	is a schematic representation of a first embodiment of the present invention;

Figure 2 is a schematic representation of an apparatus in accordance with a further embodiment of the present invention for monitoring the integrity of the structure;

Figure 3 is a schematic representation of a further embodiment of the present invention;

Figure 4a is a schematic representation of a further embodiment of the present invention;

Figure 4b is a schematic representation of a further embodiment of the present invention;

Figure 5 is a schematic representation of a two-layer sandwich structure to which an embodiment of the present invention is applied;

Figure 6 is a schematic representation of a three-layer sandwich structure to which an embodiment of the present invention is applied;

Figure 7 is a schematic representation of a four-layer sandwich structure to which an embodiment of the invention is applied;

Figure 8a is a schematic representation of a three-layer sandwich structure to which an embodiment of the present invention is applied; and

Figure 8b is a schematic representation of a three-layer sandwich structure to which a further embodiment of the present invention is applied.

Figure 1 illustrates schematically, one embodiment of a method and apparatus of the present invention for preventing the ingress of a fluid F into a structure 10. The structure 10 is a fictitious structure made up from three types of composite structure and is provided merely for the purpose of illustrating the principles of embodiments of the invention. The structure 10 has an outer skin 12 and a plurality of internal cavities 14a, 14b and 14c (hereinafter referred to in general as "cavities 14"). The actual geometry of the cavities 14 is a function of the type of composite structure 10. Cavities 14a is illustrated by composite structure 10 having internal cavities of a random configuration; cavities 14b is illustrative of a composite material having a honeycomb or cellular-type core; and cavities 14c is illustrative of a composite structure 10 having a foam core.

The structure 10 is disposed in an environment 16 containing fluid F at an ambient

pressure that acts on the structure 10. For example, the environment 16 may be the atmosphere at 4000 metres above sea level, where the fluid F is air; or the environment 16 may be the ocean at depth of 100 metres in which case the fluid F is sea water.

Apparatus 18 in accordance with an embodiment of the present invention acts to prevent or at least minimise the ingress of the fluid F into the structure 10. The apparatus 18 includes a pressure source 20 for providing a first fluid such as, air or an inert gas at a pressure higher than the pressure of the fluid F. A communication channel in the form of a conduit 22 provides fluid communication between the source 20 and one or more of the internal cavities 14 of the structure 10. If it is the case that the cavities 14 of structure 10 are all directly or indirectly in fluid communication with each other, then in order for the gas of source 20 to be in fluid communication with the cavities 14 the conduit 20 need only extend into the structure 10 to a point where it pierces the skin 12. Of course a plurality of conduits 22 can be provided between the source 20 and the structure 10. However, if the cavities 14 are not in mutual fluid communication with each other or are arranged in sealed layers or groups, the communication path of apparatus 18 can include one or more galleries or conduits 24 formed within the skin 12 that communicate with the conduit 22 thereby providing fluid communication between the gas of the source 20 and the cavities 14. Alternately small perforations can be made between the internal cavities to allow fluid communication therebetween. This may for example be achieved using a laser.

The pressure of source 20 is arranged to be greater than the pressure of fluid F (which may be either a static pressure or generated from a dynamic pressure) so as to prevent the ingress of fluid F into the cavities 14. More particularly, the pressure of source 20 is arranged to be sufficient to overcome hygroscopic force and capillarity to prevent moisture ingress into the structure 10 but is not sufficient to be detrimental to the integrity of the structure 10.

It is to be recognised that if the skin 12 is absolutely impermeable to fluid F and such does not contain any faults or does not develop any faults throughout the life of the structure 10 then the fluid F of environment 16 cannot enter the structure 10. However,

in practice, for a variety of reasons including the effects of material permeability, dynamic loading, localised impact damage, practical imperfections in the manufacture of structure 10, or the use of fasteners to fabricate the structure it is often the case that the skin 12 is, or in time becomes permeable to the fluid F.

Figure 2 illustrates an apparatus 18a that allows for the monitoring of the integrity of structure 10a. The apparatus 18a includes a fluid source 20 and a conduit 22 as in the embodiment depicted in Figure 1. In addition, the apparatus 18a also includes a monitoring device 26 for monitoring the inflow of fluid from the source 20 into the cavities 14. More particularly, the monitoring device 26 monitors for a change in the steady state rate of inflow of fluid from the source 20 into the cavities 14. In this embodiment the monitoring device 26 includes a high fluid flow impedance 28 disposed in series in the conduit 22 between the source 20 and the cavities 14, and, a differential pressure transducer 30 coupled across the impedance 28. The transducer 30 is coupled across the impedance 28 by fluid connecting ducts 32, and coupled to a display 34 by electrical conductors 36. Alternatively, the differential pressure transducer 30 coupled across the impedance 28 may be in the form of a non-electrical indicator where electrical circuitry is not desirable.

Assuming that the skin 12 of the structure 10a has some degree of inherent permeability, after initial start up of the apparatus 18a, there will be a characteristic steady state rate of seepage of fluid through and from the structure 10a. If there is a change in the permeability of the skin 12/structure 10a, there will be a corresponding increase in the rate of inflow of the fluid from the source 20 into the structure 10a. This will be monitored and detected by the monitoring device 26.

Figure 3 depicts an embodiment of the present apparatus and method when applied to a structure 10a comprising anechoic tiles 38 adhered to the hull 40 of a submarine.

A fillet of elastomeric grout 48 is deposited about the periphery of each tile in a manner so that cavities 50 are created underneath the grout 48 between adjacent tiles 38 or, under grout 48 between the edge of a tile 38 and the hull 40. The cavities 50 are

coupled to a monitoring apparatus 18b. The apparatus 18b is similar to the apparatus 18a depicted in Figure 2 and includes conduit 22 that provides a fluid communication path between the cavities 50 and gas source 20 via a series connected high fluid flow impedance 28. Differential pressure transducer 30 is coupled across the impedance 28 via ducts 32. A display 34 coupled to the transducer 30 via electrical conductors 36 provides a display of steady state pressure differential across the impedance 28. The fluid from supply 20 is metered through a pressure regulator 52 which is disposed in the conduit 22 between the impedance 28 and the source 20. The regulator 52 is also pressure referenced to the surrounding atmosphere, in this case the ocean, via a duct 54. The regulator 52 maintains the pressure of the gas from source 20 at a substantially constant level above the water pressure. As ambient water pressure varies with depth the system 18b, and in particular the regulator 52, is able to dynamically vary the pressure of the gas from source 20 delivered to the cavities 50. In operation, the apparatus 18b stabilises with a relatively constant pressure differential across the high impedance irrespective of the ambient water pressure.

The integrity monitoring of the adhesive bonding of the tiles 38 is facilitated by monitoring the differential pressure across the high impedance 28 for any increase resulting from minuscule air seepage from any of the cavities 50 giving ample warning of any disbond of a tile 38 or damage to the grout 48. The imminence of disbonding and water ingress would be immediately obvious due to a rise in pressure differential across the impedance 28 and detected by the transducer 30. Loss of a tile 38 would result in a dramatic rise in differential pressure.

The apparatus 18b can also be provided with an adjustable bypass of the impedance 28 to allow high rates of flow of air from the source 20 to allow for some damage tolerance and maintain positive pressure protection for the cavities 50. As ambient pressure surrounding the hull 40 of the submarine would vary significantly from the top of the conning tower to the belly of the hull, it may be necessary to group the tiles 38 into several vertically tiered layers which are monitored separately to ensure that the pressure of the gas supplied to a particular group of tiles remains only slightly above the ambient pressure acting on those tiles thereby preventing excess positive pressure in

upper groups of tiles. This can be achieved by providing a manifold in the portion of conduit 22 between the source 20 and regulator 52 and having a plurality of regulators 52 each feeding from the manifold and coupled to identical arrangement of high fluid flow impedance 28, transducer 30, and ambient pressure reference 54.

Figure 4a illustrates a further embodiment of the present invention applied to a structure 10c comprising three components 56, 58 and 60 which are coupled in a sandwich construction. More particularly, the structure 10c is part of a pressurised fuselage of an aircraft. The components 56, 58 and 60 are fastened together by rivets 62. Each rivet 62 has a head 64 that sits flush with the component 56 and a flattened tail 66 at an opposite end that sits on the component 60. Flush head rivets are shown as an example but round head rivets and possibly bolt fasteners could be substituted.

Sandwich components generally have a layer of a sealant material between each fastened layer. To facilitate the provision of a cavity, this arrangement is modified in the present embodiment such that a sealant layer 68 is provided between components 56 and 58 only. The interface between the components 58 and 60 does not contain a sealant leaving a gas permeable gap 70 therebetween. In accordance with the present embodiment the gap 70 can be formed into a cavity 72 by providing a perimeter seal 74 about the perimeter of gap 70. Apparatus 18c is connected to the cavity 72 for monitoring the integrity of the structure 10c. The apparatus 18c includes a conduit 22 leading to a parallel connection of high fluid flow impedance 28 and pressure transducer 30. The transducer 30 is coupled to a display 34 via electrical conductors 36. Alternatively, the differential pressure transducer 30 coupled across the impedance 28 may be in the form of a non-electrical indicator where electrical circuitry is not desirable.

The pressure source 20 of this embodiment however is cabin pressure of the aircraft which feeds into both the impedance 28 and the transducer 30. If a crack were to form in the intermediate component 58 about the rivet 62, a fluid seepage flow path can be created around the rivet 62 and end 64 to the outside atmosphere due to the crack and subsequent loosening of the fastening. The resulting increase of the inflow of air into

cavity 72 through the impedance 28 will be detected by the transducer 30 as a change in differential pressure thus providing an indication of a crack in component 58. Tests have shown that high compression forces can exist inside the hole 71 at the flattened end 66 of the rivet. However, sealant 75 may be employed if desired around the flattened end 66 and adjacent surface of component 60.

In an alternate embodiment depicted in Figure 4b, the apparatus 18d for monitoring the integrity of structure 10c comprises a compliant container 76 of a fluid marker such as a liquid or gaseous dye, or detectable gas, which is coupled by conduit 22 to the cavity 72. As with the previously described embodiment, if a crack were to develop in the component 58 that extends to the rivet 62, there will be a flow of marker from the container 76 through conduit 22, cavity 72, the crack and around rivet 62 seep to the outside atmosphere. This arises because the compliant container 76 is also subject to cabin pressure. The detection of dye or gas about the rivet 62 provides an indication of the crack in the component 58.

When the fluid marker is a liquid or gaseous dye, detection can be by means of visual inspection of the structure. The appearance of the dye say around the head of a rivet 62 is indicative of gas seeping from about the rivet potentially due to the existence of a crack. When a detectable gas is used as the marker such as helium, gas monitoring and detecting equipment is required to detect the escape of the gas from the structure. In the case where the structure has some inherent permeability, there will be of course a steady state flow of the gas through the structure in which case one is required to monitor for a change in the steady state condition. On the other hand, if the structure is absolutely impermeable, then one is required to detect for any presence of the gas marker. This of course is the same as monitoring for a change in the steady state flow where the steady state flow is zero.

Figures 5-7 depict variations of "sandwich" structures to which embodiments of the present invention can be applied.

In Figure 5, structure 10d comprises two components 56 and 60 fastened together by

rivets 62. A gas permeable gap 70 exists between mutually facing adjacent surfaces of components 56 and 60. A cavity 72 is formed by sealing the gap 70 with a perimeter seal 74. The structure 10c is either disposed in an environment of, or otherwise acted upon by, a fluid F at an ambient pressure. The integrity of the structure 10d can be monitored by connecting the cavity 72 via a conduit 22 to an apparatus 18 of the type described hereinabove.

As the cavity 72 in the structure 10d is completely enveloped by the fluid F, any seepage of gas from the cavity 72 will be to the surrounding environment.

In Figure 6, the structure 10e is very similar to the structure 10c in Figure 4a. However the structure 10e is now formed with two cavities, 72_s is formed between mutually adjacent faces of components 56 and 58 of the structure 10e. The cavities 72_s are in fluid communication via conduit 22 with the pressure source 20 (not shown) of an apparatus 18 (not shown) coupled with conduit 22. The cavity 72_e however which exists between components 58 and 60 is placed in fluid communication with the fluid F, ie the cavity 72_e is now pressure referenced to the environment. This now allows for a detection of a crack or other fault in the intermediate component 58 that extends between the cavities 72_s and 72_e, but not directly to the "environment".

Figure 7 depicts a further sandwich structure 10f having four layers or sheets 56, 57, 58 and 60 connected together by rivets 62. Layer 57 comprises two abutted sheets. The method of monitoring the integrity of structure 10e includes forming cavities 72_s that are in fluid communication with the pressure source 20 of an apparatus 18 of the type described hereinabove and forming cavities 72_e that are in fluid communication with the environment or a source of ambient pressure, with a cavity 72_e interspersed with a cavity 72_s.

Figure 8a depicts a further embodiment of the invention. This embodiment is applied to a structure 10g comprised of three sheets 56, 58 and 60 formed as a sandwich construction coupled together by rivets 62. As explained in relation to the embodiment depicted in Figure 4a, it is common for such structures to incorporate a layer of sealant

material 68 between adjacent sheets. The layer 68 is typically provided to prevent fretting of the sheets 56, 58, 60 about the rivets 62. In the present embodiment, the step of providing cavity 72 within the structure 10g involves removing sections of the sealant 68 between adjacent pairs of sheets. However areas of sealant 68 are maintained about the rivets 62 to maintain the function of minimising fretting of the sheets 56, 58, and 60, and also to form boundary seals for the cavities 72. The removed sealant 68 produces the sealed cavities 72 which can be placed in fluid communication with a pressure source 20 (not shown). Indeed alternate cavities 72 can be placed in fluid communication with the atmosphere and with the source as described above in relation to the embodiments depicted in Figures 6 and 7. The removal of the sealant 68 to produce the cavities 72 is ideally achieved during the construction of the structure 10g by placing masks on the sheets 56, 58 and 60 to prevent the depositing of sealant 68 in selected regions. After the sealant layer 68 has been applied and the masks removed, the structure 10g is pulled together by fastening with rivets 62.

Figure 8b depicts a structure 10h which differs from that depicted in Figure 8a by the inclusion of recesses or depressions 80 deliberately formed in the surface of the sheets 56, 58 and 60 in the regions where the sealant 68 is removed. This provides larger, more definite cavities 72. The recesses or depressions 80 can be formed by any known means including but not limited to, chemical milling. The cavities 72 can be placed in fluid communication with a source 28 (not shown) by conduits 22 (not shown) in the manner described hereinabove in relation to Figures 4a-7. Of course in a further variation alternate cavities 72 can be placed in communication with the source 20 and the ambient pressure.

Now that the embodiments of the present invention have been described in detail it will be apparent to those skilled in the relevant arts that numerous modifications and variations may be made without departing from the broad inventive concepts. For example, a moisture trap can be provided between the source 20 and impedance 28, when the source 20 is a gas source to dry the gas prior to flowing into the structure 10. Further, the source 20 can be the source of an inert gas. When the structure 10 is a composite material having a plurality of internal cavities that are sealed from each other,

embodiments of the invention include forming communication paths in the composite material between the internal cavities.

All such modifications and variations are deemed to be within the scope of the present invention the nature of which is to be determined from the above description.

Dated this 8th day of September 2000

STRUCTURAL MONITORING SYSTEMS LTD
By its Patent Attorneys
GRIFFITH HACK
Fellows Institute of Patent and Trade Mark
Attorneys of Australia

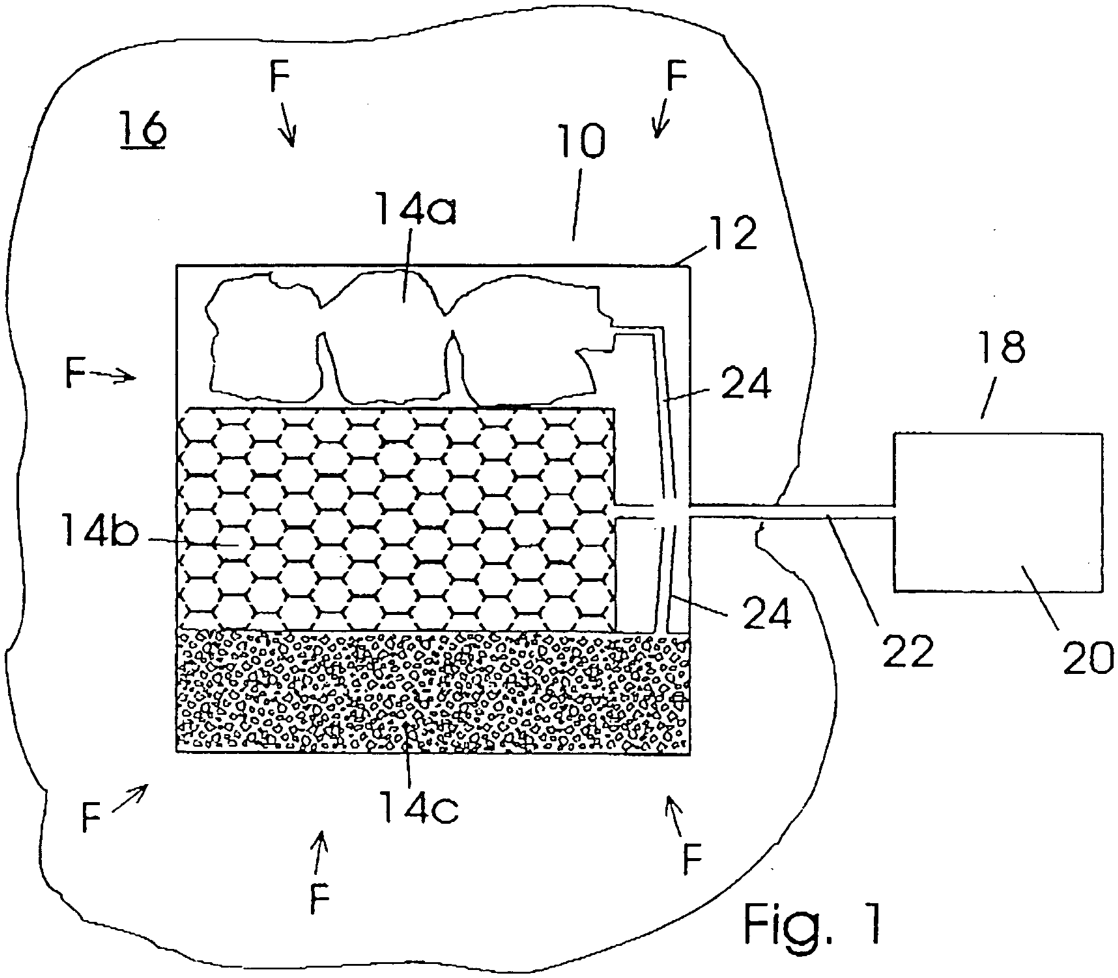

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Fig. 1

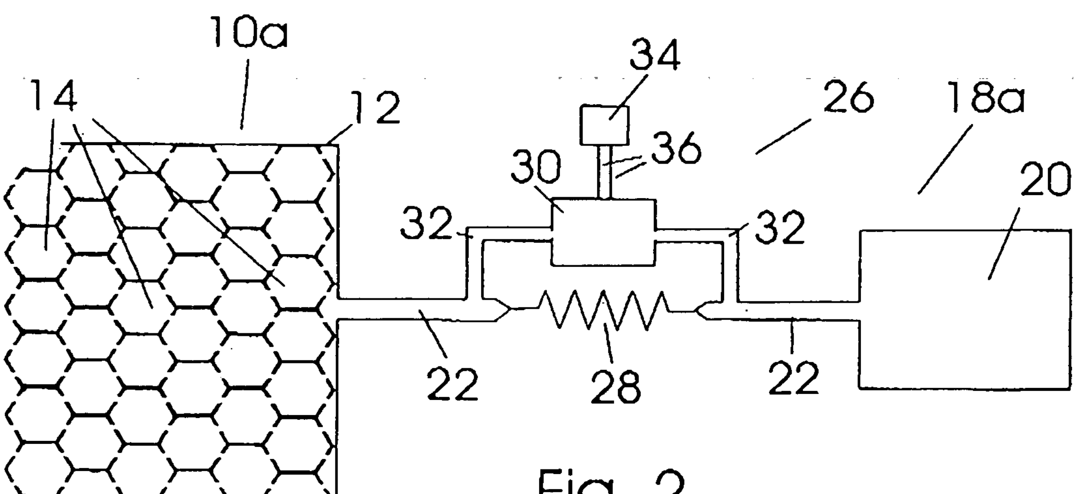

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Fig. 2

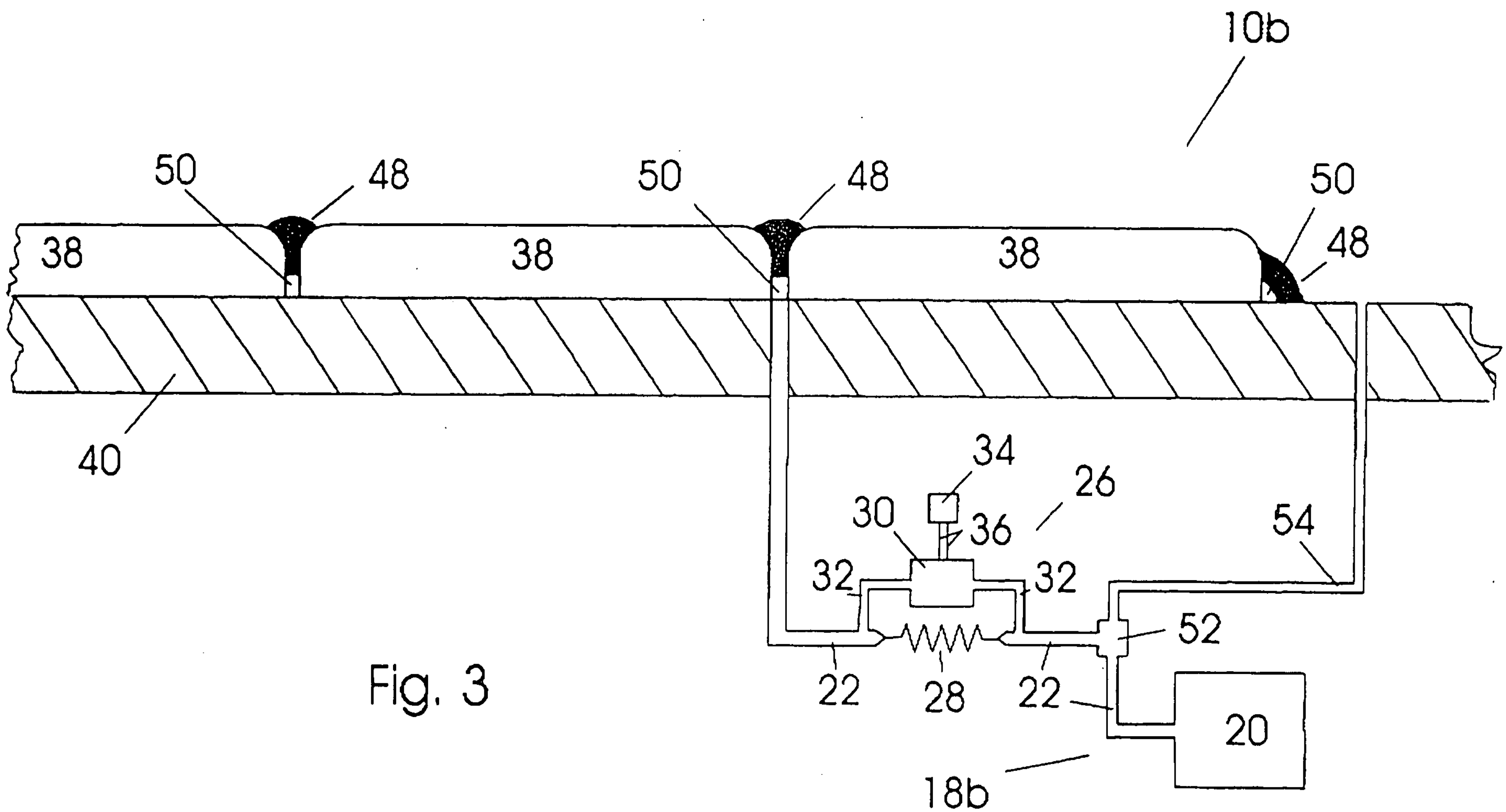
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Fig. 3

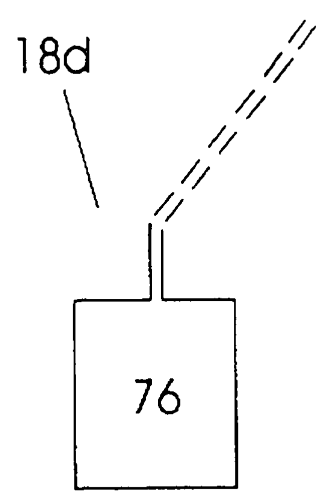
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Fig. 4b

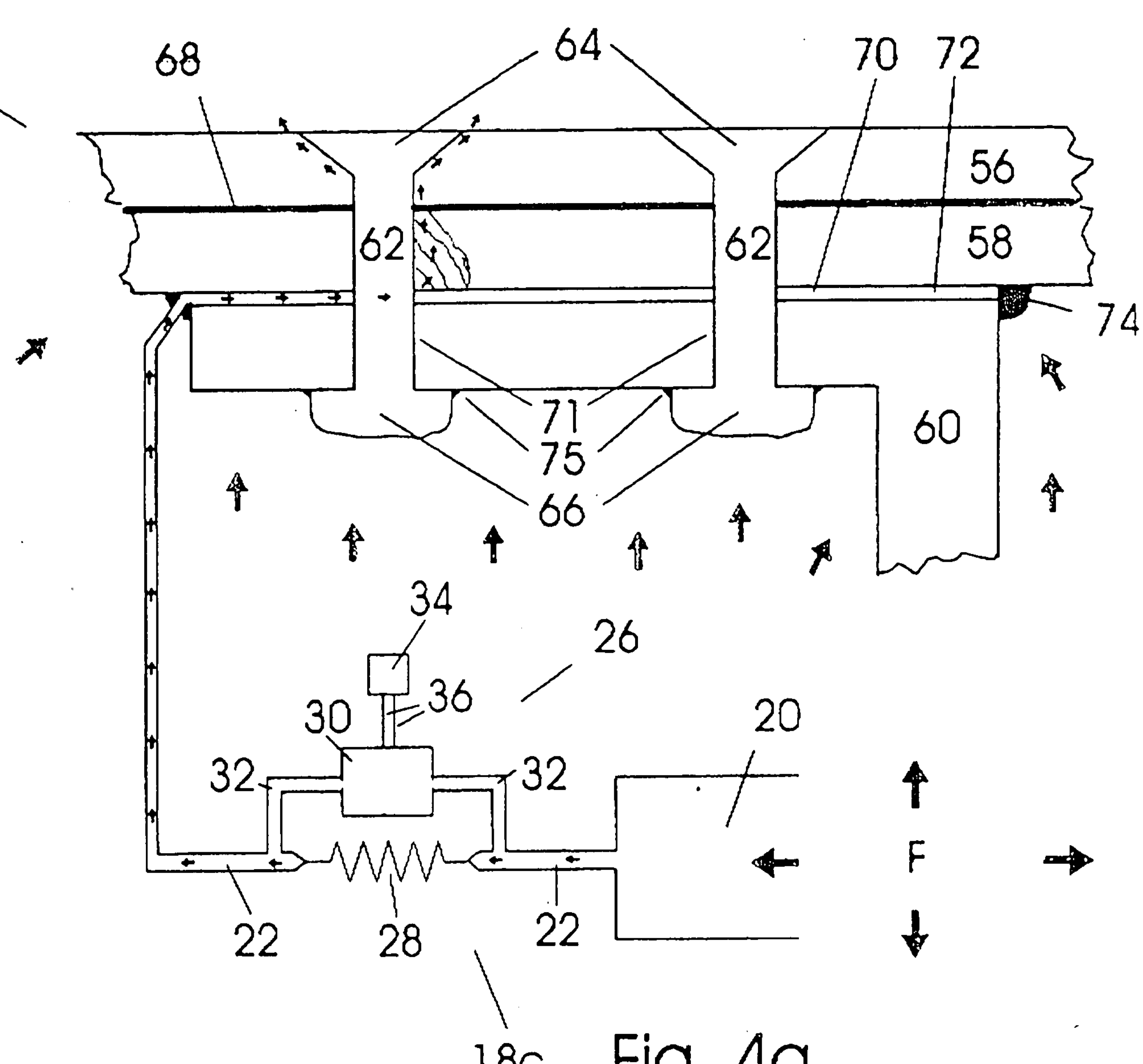
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Fig. 4a

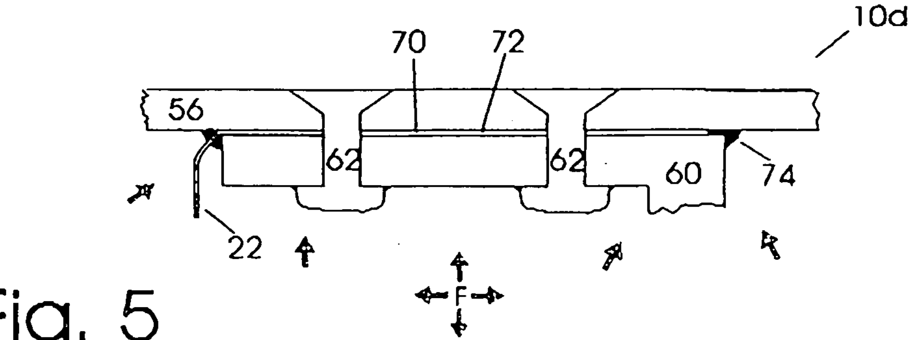

Fig. 5

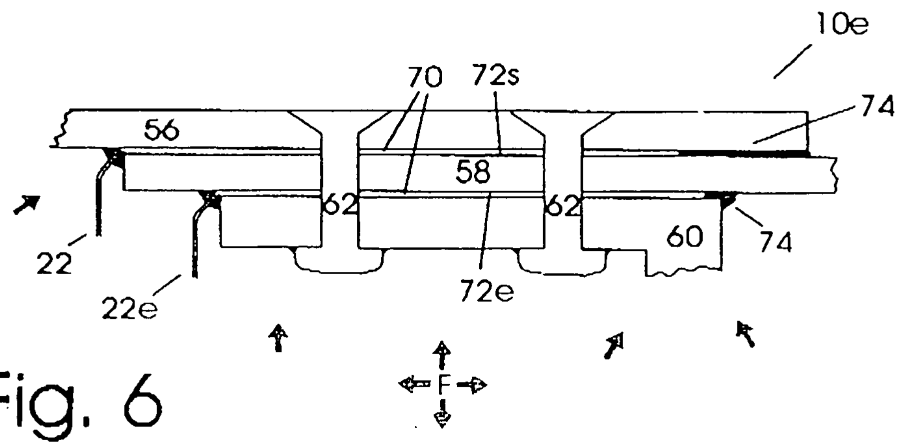

Fig. 6

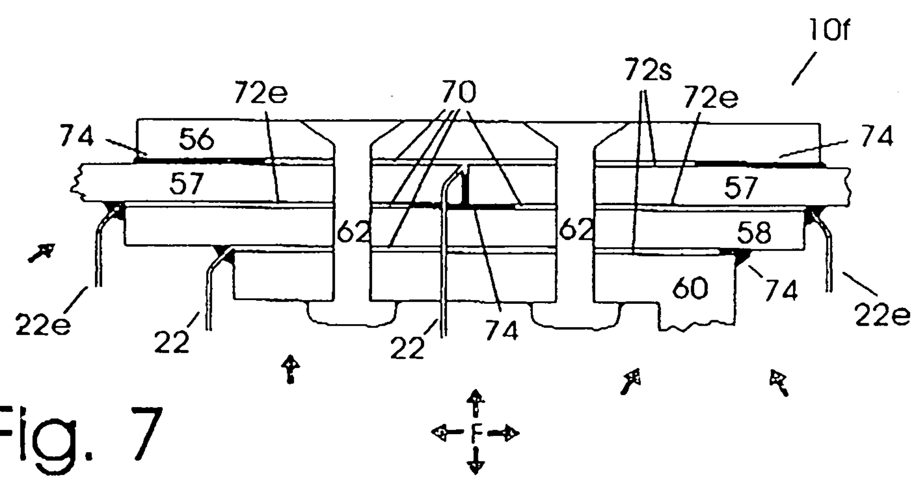

Fig. 7

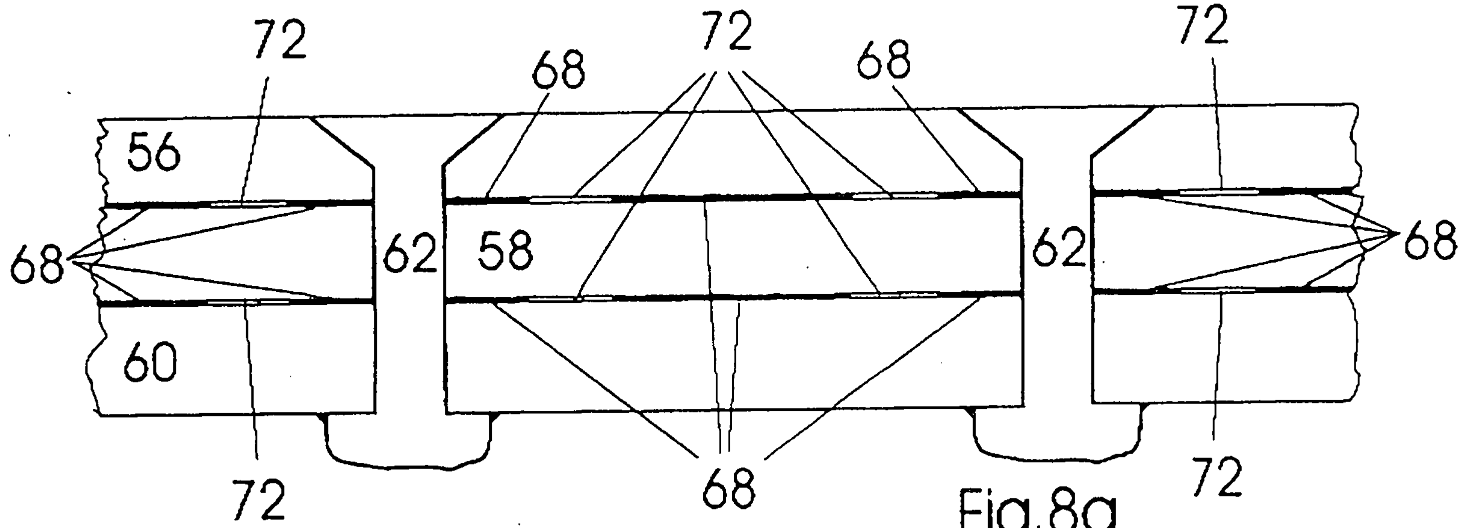

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Fig.8a

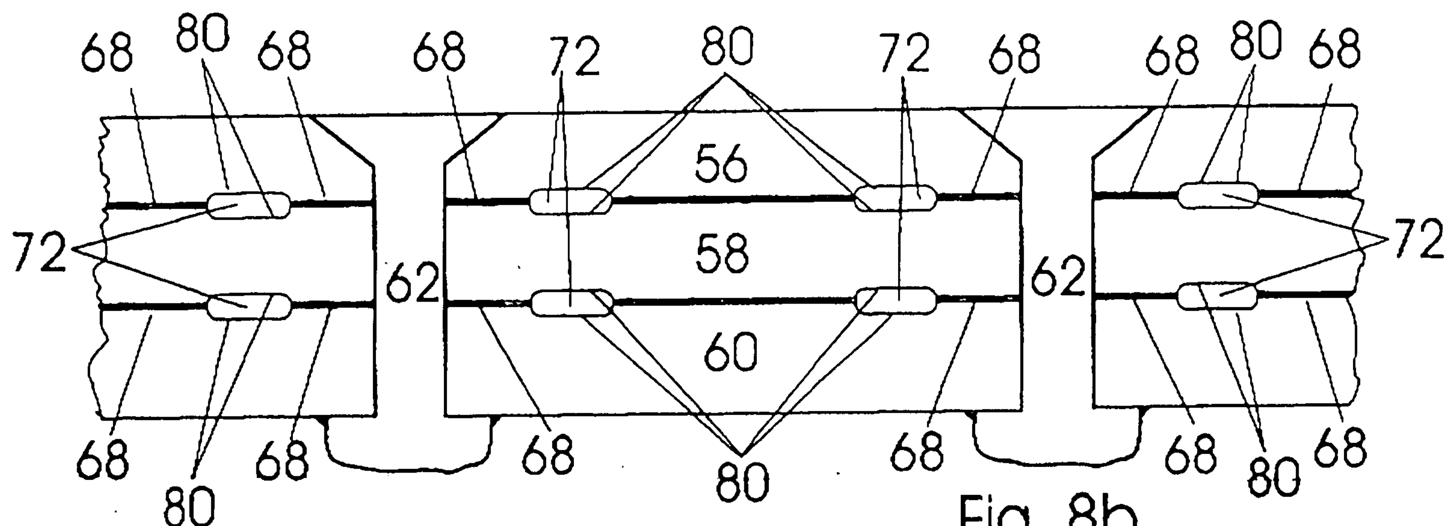

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Fig. 8b